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PHENIX Results on Jet Correlations versus Reaction Plane

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Abstract. In relativistic heavy-ion collisions, studying jet correlations and their dependence on the angle of emission with respect to the reaction plane can be used to shed light on the path length dependence of the energy lost by the jet. In this paper, we present recent PHENIX results on jet correlations versus reaction plane, as a function of centrality and transverse momentum.

1. Introduction

Jet production from the hard-scattering of partons in relativistic heavy ion collisions at RHIC is an important observable for the strongly interacting matter created. The observation of jet quenching in particular has provided key insight into the produced medium and its response to energy lost by fast partons as they traverse it. The partons' energy loss is predicted to be dependent on gluon densities and the path length traversed by the jet. Because of the difficulty of full jet reconstruction in the high multiplicity environment of a heavy ion collision, azimuthal correlations are a crucial tool for extracting such jet properties.

For each event, correlations in azimuthal angle ϕ are constructed by selecting the leading (high-p_{T}) particle (called the *trigger* particle) and other particles in the event (called the *associated* particles)[1]. Subsequent to hard-scattering, the partons fragment into a cone of hadrons which are the particles observed in the laboratory. The trigger particle serves as a proxy for the jet axis. As a result, we expect to find peaks at $\Delta\phi = 0$ and $\Delta\phi = \pi$ (where $\Delta\phi = \phi_{trig} - \phi_{assoc}$), corresponding to the jet of the trigger particle and the momentum-balanced jet on the away-side respectively. This is illustrated in Figure 1, and has been observed in p+p collisions [2]. Also shown in Figure 1 is the two-particle correlation function in heavy-ion collisions.

A striking feature of the jet-induced angular distributions is the modification of the away-side peak [1, 4] as seen in Figure 1. A number of models have been
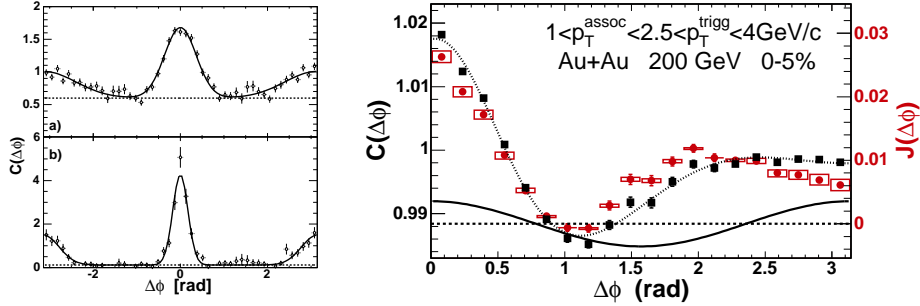
Fig. 1. Left: Measured two-particle correlations for p+p collisions at RHIC, for both particles in the momenta ranges of a) $1.5 < p_T < 2.0$ GeV/c and b) $3.0 < p_T < 4.0$ GeV/c. Data and fits are described in Ref. [2]. Right: Measured correlation and jet functions for central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [3].

proposed to explain the structure of the away side peak, including Mach cone/sonic boom scenarios[5, 6, 7], Cherenkov radiation [8], and coupling of jets and flow [9], to name a few.

The key to understanding the sources of energy loss, and therefore the ability to constrain any of these models, is the need to control the geometry of the collision. Centrality selection constrains the energy density of the collision, but that is not quite sufficient. If we further choose orientations of the trigger particle with respect to the reaction plane, this has the effect of varying the effective path length of the jet. The combination of centrality and trigger particle orientation will constrain the path length dependence of the energy loss, enabling the ability to untangle jet and medium responses.

2. PHENIX Measurements

Data taken from three separate years of RHIC operation have been studied as a function of trigger particle orientation: Au+Au at $\sqrt{s_{NN}} = 200$ GeV/c collisions from Run-4 and Run-7 (taken during 2004 and 2007 respectively), and Cu+Cu at $\sqrt{s_{NN}} = 200$ GeV/c collisions from Run-5 (taken during 2005).

The PHENIX detector [10] consists of mid-rapidity spectrometers covering $|\eta| < 0.35$ and forward arms with acceptance of $1.2 < |\eta| < 2.4$. Hadrons are measured in the central arms using drift chambers, a ring-imaging cerenkov, and electromagnetic calorimetry. For heavy-ion collisions, centrality is determined from the correlation between the beam-beam counters (BBCs, located at $3.0 < |\eta| < 4.0$) and zero-degree calorimeters (Au+Au, Run 4) or from the BBCs alone (Cu+Cu, Run5 and Au+Au, Run 7). The reaction plane in PHENIX can be measured in multiple complementary detectors. For the data presented in this paper, the reaction plane orientation Ψ_{RP} is determined event-by-event based on the angular distribution of hits in the BBCs (Run 4 and Run 5) or the Reaction Plane Detector

(installed prior to Run 7), using the standard method described elsewhere[11]. Non-flow effects on the reaction plane determination have been studied, and it has been estimated that little to no bias exists in the current measurements [1].

To determine the jet-induced angular distributions, PHENIX adopts a two-source model for the source of correlations: hard scattering (jets) and collective behavior (elliptic flow, characterized by v_2). Extraction of the jet function in these collisions requires careful subtraction of the background. The technique used in the data presented is the Zero Yield at Maximum (ZYAM)[4]. The key feature of ZYAM is that it assumes there is a value of $\Delta\phi$ where the jet yield is zero, and uses that point to constrain the background (v_2 modulation) level. To study the dependence on orientation with respect to the reaction plane, the trigger particles have been placed into six and three $\Delta\phi_{RP} = \phi_{trig} - \Psi_{RP}$ bins from 0 to $\pi/2$ for Au+Au and Cu+Cu collisions, respectively.

3. Results and Discussion

Run-4 Au+Au correlation and jet functions measured for 0-5% and 30-40% events are shown in Figure 2. For the correlation functions the different curves correspond to the trigger particle orientation, from 0 (red, or the curve corresponding to the maximum value at $\Delta\phi = 0$) to $\pi/2$ (cyan, or the curve with minimum value at $\Delta\phi = 0$). Several conclusions can be drawn immediately. First, there is significant dependence on trigger orientation in the correlation functions, but after subtraction, there is little evidence of any dependence. Also, the same trends in the data can be seen in both central and semi-central events. In particular the shoulder that emerges after subtraction remains the same, independent of either centrality or trigger orientation. These features persist in the Run-7 results, which benefit from higher statistics and higher resolution reaction plane measurement, as seen in Figure 3. These trends have been reported for Au+Au collisions observed at STAR[12] as well. Similar observations have been made using Cu+Cu jet functions, shown in Figure 4. Like the Au+Au data, there is no observed dependence of the away-side shape. Within errors, the location of the excess is independent of centrality and trigger orientation.

The persistance of the away-side shape and the shoulder location in $\Delta\phi$ has important consequences on energy loss models. The shoulder region is insensitive to the path length variation, thus disfavoring jet-flow coupling scenarios. This feature, however, does tend to support mach-cone models. The head region ($\Delta\phi \sim 2\pi$) does appear to be sensitive to the path length, which is consistent with energy loss expectations. Additionally, it has been shown that the away-side shape parameters (RMS, kurtosis, and D) are independent of system size and saturate for $N_{coll} > 100$[3]. This observation both disfavors Cherenkov gluon radiation and offers constraints to other models, such as large-angle non-Cherenkov radiation. Figure 5 shows the dependence on trigger orientation for the aways-side RMS, kurtosis, and D parameters for Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV/c. Within systematics, there
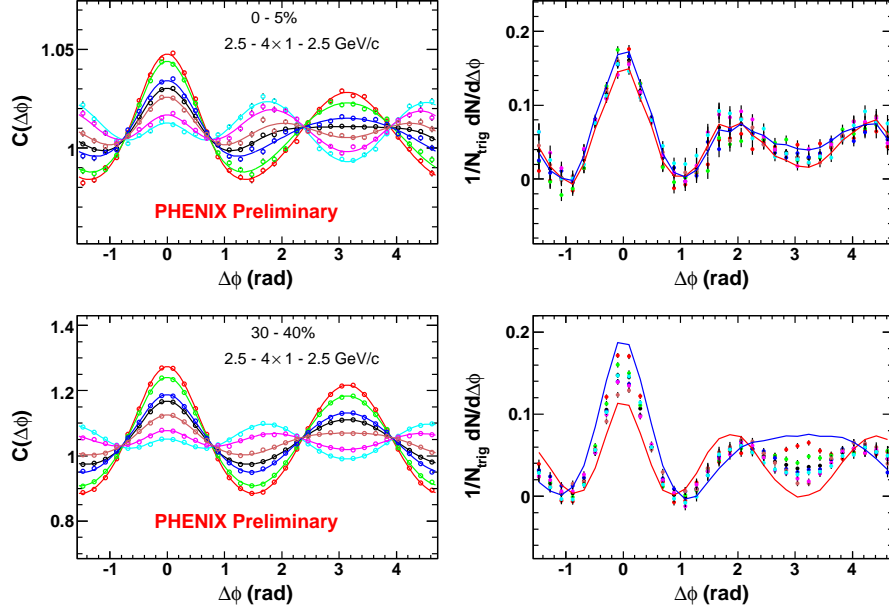
Fig. 2. Correlation functions (left) and jet-induced yields (right) for 0-5% and 30-40% centralities in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV/c. Data are from Run-4.

is no reaction-plane dependence.

The ZYAM method admittedly has its limits; there is no a priori reason to the believe that the assumption of zero yield is a particularly accurate one. However, even with this caveat, it is impossible to ignore the non-trivial shape of the away-side yields. This is because an excess in the shoulder region is observed even before subtraction, as seen in Figure 6. To make this point as clear as possible, in the left panel we have chosen a trigger orientation that should suffer from the least bias v_2 determination. Shown are correlations in several centrality bins. Clearly even before subtraction, a significant excess is seen at $\Delta\phi \sim 2$.

4. Conclusions

In summary, the heavy-ion data measured at RHIC have displayed a evolution of the away-side peak shape with p_T. A key to understanding these trends is using the orientation of the trigger particle in azimuthal correlations to constrain the effect path length of the fast partons traversing the medium. Recent measurements at PHENIX show that the shoulder of the away-side peak, observed at low to intermediate p_T, appears at the same position ($\Delta\phi \sim 2$), regardless of the centrality, system size, and orientation of the trigger particle with respect to the reaction plane. These data then provide critical contraints and insights into understanding
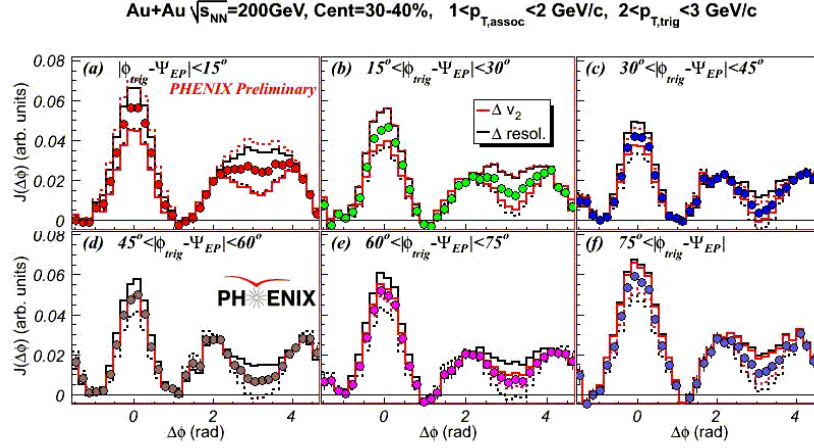
Fig. 3. Jet-induced yields for 30-40% centrality in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV/c. Data are from Run-7.
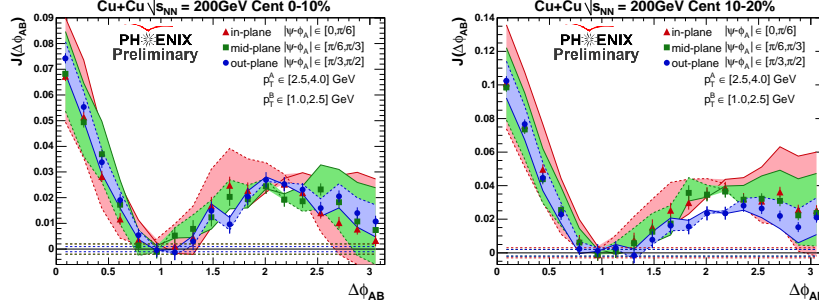

Fig. 4. Jet-induced yields in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ GeV/c. Data are from Run-5.
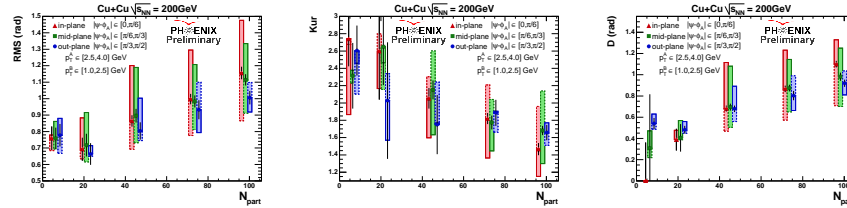

Fig. 5. (Left to right) The away-side RMS, kurtosis, and D shape parameters for Cu+Cu collisions as a function of centrality, in different $\Delta\phi_{RP}$ bins.
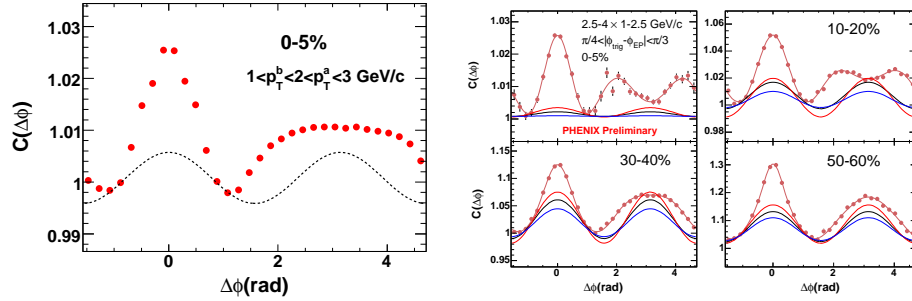
Fig. 6. Left: Inclusive correlation function for 0-5% Au+Au collisions. Right: correlation functions as a function of centrality for trigger orientation $\pi/3 < \Delta\phi_{RP} < \pi/4$. The curves show the strength of the v_2 along with the bounds of uncertainty on the v_2 determination.

the various energy loss models proposed as explanations for the trends seen in the away-side measurements.

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